MSFC-096

A NEW HEAVY-LIFT CAPABILTIY FOR SPACE EXPLORATION:

NASA'S ARES V CARGO LAUNCH VEHICLE

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ABSTRACT

The National Aeronautics and Space Administration (NASA) is developing new launch systems and preparing to retire the Space Shuttle by 2010, as directed in the United States (U.S.) Vision for Space Exploration. The Ares I Crew Launch Vehicle (CLV) and the Ares V heavy-lift Cargo Launch Vehicle (CaLV) systems will build upon proven, reliable hardware derived from the Apollo-Saturn and Space Shuttle programs to deliver safe, reliable, affordable space transportation solutions. This approach leverages existing aerospace talent and a unique infrastructure, as well as legacy knowledge gained from nearly 50 years' experience developing space hardware. Early next decade, the Ares I will launch the new Orion Crew Exploration Vehicle (CEV) to the International Space Station (ISS) or to low-Earth orbit for trips to the Moon and, ultimately, Mars. Late next decade, the Ares V's Earth Departure Stage will carry larger payloads such as the lunar lander into orbit, and the Crew Exploration Vehicle will dock with it for missions to the Moon, where astronauts will explore new territories and conduct science and technology experiments. Both Ares I and Ares V are being designed to support longer future trips to Mars. The Exploration Launch Projects Office is designing, developing, testing, and evaluating both launch vehicle systems in partnership with other NASA Centers, Government agencies, and industry contractors. This paper provides top-level information regarding the genesis and evolution of the baseline configuration for the Ares V heavy-lift system. It also discusses risk-based-management strategies, such as building on powerful hardware and promoting common features between the Ares I and Ares V systems to reduce technical, schedule, and cost risks, as well as development and operations costs. Finally, it summarizes several notable accomplishments since October 2005, when the Exploration Launch Projects effort officially kicked off, and looks ahead at work planned for 2007 and beyond.

INTRODUCTION

The strategic goals outlined in the U.S. Vision for Space Exploration (January 2004) guide NASA's challenging missions of scientific discovery.[1] In addition, the U.S. Space Transportation Policy (December 2005) directs America's civil space agency to provide launch vehicle systems for assured access to space.[2] The Vision provides specific guidelines for relatively near-term human exploration of the Moon to prepare astronauts for longer journeys to Mars. It also commits the United States to completing the International Space Station and retiring the Space Shuttle by 2010. New space transportation systems will provide new capabilities for the human exploration of space beginning as soon as possible after the Shuttle is retired.

The Ares I is slated to fly the Orion CEV in the 2014 timeframe, while the Ares V is slated to fly the Lunar Surface Access Module (LSAM) by 2020. Both are shown in Figure 1. These systems are being designed for safe, reliable, and sustainable space transportation by building on a foundation of legacy knowledge and heritage hardware, while reflecting modern engineering

and business best practices that meet stringent standards and deliver maximum value for the investment. Together, these space transportation systems will replace the Space Shuttle for the human exploration of Earth's cosmic neighborhood and beyond.

Figure 1. Ares V (left) and Ares I in flight (artist's concept).

RESULTS AND DISCUSSION

RISK–BASED TECHNICAL AND MANAGEMENT APPROACH

The Exploration Launch Projects Office has been chartered by the Constellation Program, located at NASA's Johnson Space Center, and the Exploration Systems Mission Directorate, located at NASA Headquarters, to deliver safe, reliable crew and cargo launch vehicles designed to minimize life-cycle costs so that NASA can concentrate its resources, both budget and personnel, on missions of scientific discovery. To that end, the Space Shuttle follow-on systems are being designed and developed to maximize safety and reliability margins, with an eye on affordability of near-term development and long-range operations activities.

Toward that end, engineers and managers are working to transfer hardware, infrastructure, workforce, and decades of experience from the Space Shuttle Program to the new launch systems. The Ares government/industry team also has tapped into Saturn databases and sought insights from Apollo-era veterans. Learning from its successes and failures, NASA is using rigorous systems engineering and systems management processes and principles to further improve the possibility of mission success.

With a "test as you fly" philosophy, the Exploration Launch Projects Office draws on analysis from computer-aided modeling and simulation applications that test integrated avionics software and simulate vehicle dynamics. The Exploration Launch Projects team also gains insight into three-dimensional configurations from subscale wind tunnel model testing. These preliminary analyses lead to real-world testing with increasingly flight-like hardware to gain confidence in the systems before orbital flight tests that will yield even more information on which to base critical hardware and operations decisions.

Using rigorous systems engineering standards and guidelines provides a framework for both internal and external independent reviews, with clearly defined entrance and success criteria

on which to base decisions.[3] Major milestone reviews help guide engineers to a configuration that that fulfills customer and stakeholders requirements on time and within budget.

THE ARES V DESIGN CONCEPT AND MISSION SCENARIO

The Ares V has undergone a series of concept studies to determine the most appropriate vehicle design for the requirements levied by the missions ahead. A side-by-side expanded view of the current Ares I and Ares V baseline configurations for lunar missions is shown in Figure 2. The Ares V consists of two Shuttle-derived 5-segment Reusable Solid Rocket Boosters (RSRBs) using polybutadiene acrylonitrile (PBAN) propellant, similar to the Ares I first stage. The Ares V core stage is a 33-foot-diameter tank delivering liquid oxygen and liquid hydrogen (LOX/LH2) to a cluster of five RS-68 engines. The Ares V Earth Departure Stage (EDS), which carries payloads such as the Lunar Surface Access Module (LSAM), employs the same J-X Upper Stage Engine as the Ares I Upper Stage. The LOX/LH2 J-2X is a derivative of the Saturn upper stage engines. This hardware commonality is expected to reduce both development and operations costs.

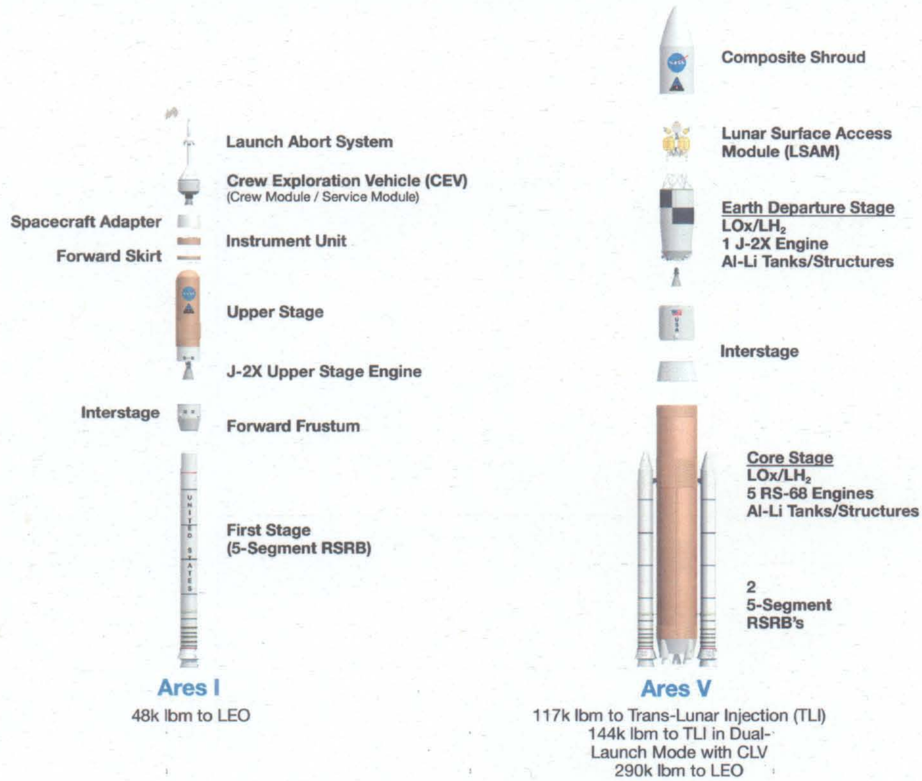

Figure 2. Expanded views of Ares I and Ares V.

The lunar mission scenario is shown in Figure 3. During ascent, the Reusable Solid Rocket Boosters separate from the Core Stage. After separation from the spent Core Stage, The EDS will ignite and place the vehicle into a circular orbit, discarding its payload shroud and exposing the LSAM. The Orion CEV, delivered to orbit by the Ares I, will dock with the EDS/LSAM. The EDS J-2X engine will re-ignite to start Trans Lunar Injection. The EDS will be jettisoned when the mated crew and lunar modules are on course for the Moon. Once the astronauts arrive in lunar orbit, they will check out systems, transfer to the lunar lander, and descend to the Moon, while the crew module remains in orbit. At the end of their lunar stay, the astronauts will return in the lunar lander and rendezvous with the crew module to return to Earth.

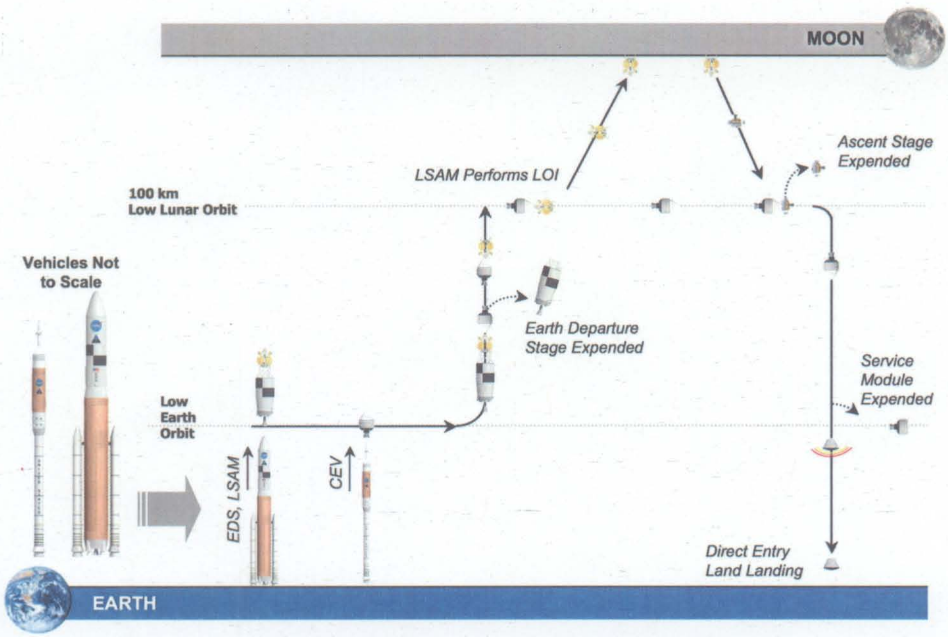

Figure 3. Lunar mission scenario.

EXPLORATION SYSTEMS ARCHITECTURE STUDY INITIAL RECOMMENDATIONS

To provide a frame of reference for the current Ares V baseline configuration, it is useful to review the genesis and evolution of the concept over the past two years. The Exploration Systems Architecture Study (ESAS) team was chartered in spring 2005 to develop and assess viable launch system configurations for a Crew Launch Vehicle and a Cargo Launch Vehicle to support lunar and Mars exploration and provide astronaut access to the International Space Station.

The ESAS team, which was comprised of government aerospace experts, developed potential launch vehicle design concepts; assessed dozens of candidate concepts against figures of merit (safety, cost, reliability, and extensibility); identified and assessed vehicle subsystems and their allocated requirements; and developed viable development plans and supporting schedules to minimize the gap between Shuttle retirement and the Orion's initial operational capability. The study team explored concepts derived from elements of the existing Evolved Expendable Launch Vehicle (EELV) fleet and the Space Shuttle.

In fall 2005, the Exploration Systems Architecture Study team released a report that recommended a heavy-lift launch vehicle configuration.[4] This point-of-departure vehicle was based on two 5-segment Reusable Solid Rocket Boosters and five Space Shuttle Main Engines (SSMEs) modified to be expendable rather than reusable, a 27.5-foot-diameter core tank derived from the Shuttle's External Tank, and the J-2S+ upper stage engine.

BOTTOM-UP REVIEW REFINES CONCEPT

Following the Exploration Systems Architecture Study, in spring 2006, the Constellation Program tasked the Exploration Launch Office with performing follow-on studies of technical scope as it relates to budget guidelines and schedule targets.

As a result of this comprehensive bottom-up review, the Constellation Program adopted a revised vehicle configuration based on analyses performed by rocket engineers and business professionals, which gave clear evidence that the RS-68 engine could offer significant savings over redesigning the reusable Space Shuttle Main Engine — a complex, reusable, human-rated engine — for this Ares V expendable application.[5]

Developed by Boeing (Pratt & Whitney Rocketdyne) for the U.S. Air Force's EELV Program, the RS-68, shown during development in Figure 4, now powers the Delta IV launch vehicle family. The RS-68 is the most powerful liquid oxygen/liquid hydrogen engine in existence. When modified to meet NASA's standards, the five-engine cluster/33-foot-diameter tank will exceed the Constellation Program's payload lift requirements. Building on lessons learned from the SSME Project, the development time for the relatively new RS-68 was cut in half and the parts count was reduced by 80 percent. Touch labor for the RS-68 was reduced by 92 percent over the labor-intensive SSME processing, and non-recurring costs were cut by 20 percent.[7] Collaborating with the U.S. Air Force on RS-68 engine upgrades will reduce cost and risk to the Constellation Program. Flights of upgraded RS-68 engines on the Delta IV will provide performance data that will further reduce technical risk.

The review also validated the use by both vehicles of the same Reusable Solid Rocket Booster and upper stage engine, which offers multiple benefits, including reduced recurring and nonrecurring operations costs.

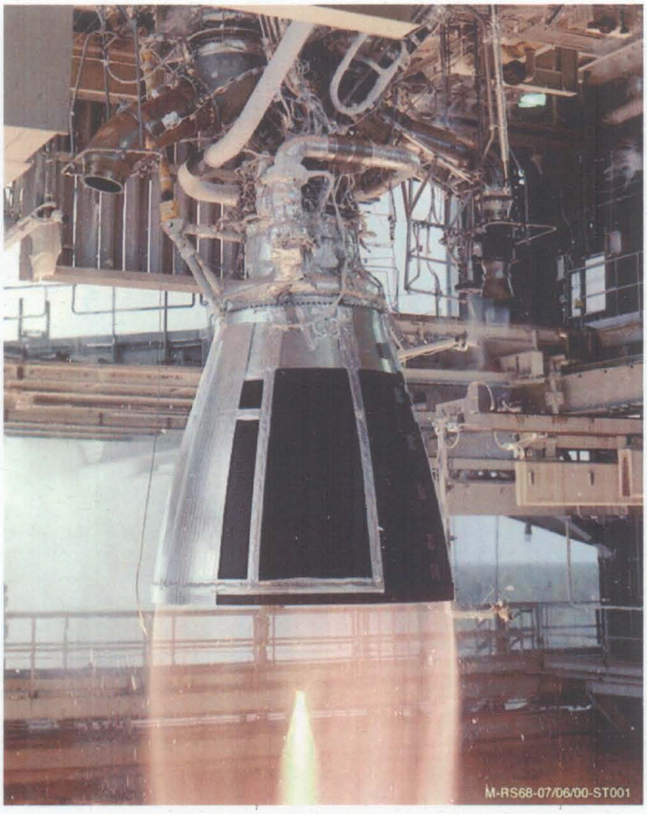

Figure 4. RS-68 engine test at Stennis Space Center in 2000.

COMMONALITY ASSESSMENT

The Commonality Assessment, conducted in May 2006, brought together a multi-disciplined panel of aerospace experts, some with Saturn and Shuttle experience, to assess potential synergy points and design challenges between the Ares I and Ares V vehicles.[6] Driven by the upcoming Ares I System Requirements Review (SRR) and Ares V Initial Requirements Review (IRR), the panel was chartered to help determine which Ares V requirements might have the most impact on the desired commonality of hardware systems and components between it

and the Ares I. Challenges and risks identified during the process led to follow-on analyses to support the Design Analysis Cycle leading to the Ares I System Requirements Review in fall 2006.

The Commonality Assessment Report results were used to perform advanced concept studies using the Vehicle Integrated Performance Analysis (VIPA) modeling and simulation capability, along with other systems engineering tools and activities, to further validate the design configuration.

Mission considerations evaluated by the commonality assessment included the three potential payloads for the Ares V: the LSAM for lunar missions, cargo to orbit, and the potential for a single-launch solution to the Moon in which the Orion and LSAM are both launched aboard the Ares V. Each payload will require different interfaces, servicing, ground and mission operations, and induced environment analyses.

The commonality assessment also examined the key goal of common hardware. There is great potential for commonality between the Ares I and Ares V Reusable Solid Rocket Boosters, including case, joint, and seal hardware; parachute and recovery systems; documentation; planning, inspection, and verification procedures; design tools; full-scale test facilities; manufacturing processes, tooling and facilities; ground support equipment, etc. However, the Ares V team will have to account for several major differences: physical stresses due to different physical configurations and flight profiles, thrust trace, tail-off and separation, potential thrust imbalance, thermal protection systems, and the sequencing of booster recovery.

The Commonality Assessment panel discussed modifying the off-the-shelf RS–68 engine for use in the Ares V Core Stage, both for performance gains and for safety improvements. A number of changes are necessary to mitigate or eliminate known issues — chiefly, reduction of free hydrogen at engine start and the engine's current excessive helium requirements for operations.

The assessment also highlighted the possibility for the RS-68 and J-2X engines to utilize common components and software for the engine controller, as well as instrumentation, pyrotechnic igniters, and ancillary components such as check valves, solenoid valves, and so forth. In addition to subsystem components, the two engines could pursue common manufacturing processes.

PROGRESS AND PLANS

This section highlights a range of accomplishments in 2006 and 2007 that advanced the Ares V design and provides a look ahead to future tasks. Although it will be a number of years before the Ares V begins flying missions to the Moon, the initial planning effort has received "seed money" to begin the lengthy process of designing, developing, and fielding a new heavy-lift launch vehicle system. A notional schedule is provided in Figure 5. Because the Ares V launch vehicle shares common hardware with the Ares I, as discussed above, it benefits from work currently being performed on those elements as part of the Ares I design, development, testing, and evaluation process.

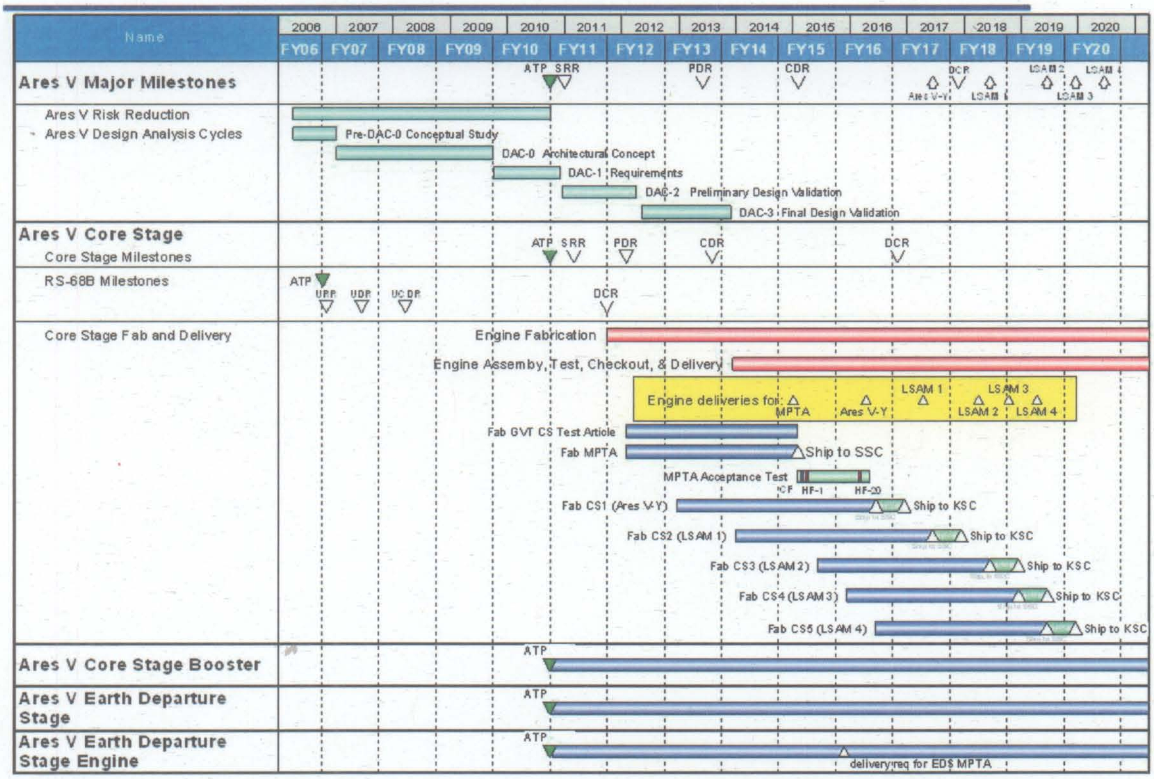

Figure 5. Ares V Summary Schedule.

Throughout 2006, the Ares V team performed comprehensive programmatic and technical planning, including developing a preliminary integrated master schedule and projecting resources — personnel, facilities, and budget. It also kicked off a number of in-house tasks and business development activities related to the RS-68 engine and the 33-foot-diameter core stage tank. The team drafted its concept of operations document as a foundational piece of information upon which trade studies aimed at defining and refining mission scenarios will build. The team visited the Michoud Assembly Facility and the Stennis Space Center test stands to gain a firsthand understanding of capabilities and constraints, such as transitioning from SSME testing to J-2X engine testing, followed by RS-68 engine testing, which will overlap with the earlier J-2X engine development, qualification, and certification.

In spring, 2006, a request for information was issued to the aerospace community for strategic input on manufacturing the Ares I Upper Stage, an in-house NASA design that also will inform and influence the Ares V Earth Departure Stage design. Responses received addressed business and technical challenges relevant to both Upper Stage and EDS design, including procurement of combined avionics, on-board electrical flight controls and guidance systems, commonality of design tools and software, ways of reducing component life-cycle costs, etc.

In April 2006, a 2-minute test of a Space Shuttle Reusable Solid Rocket Booster was performed at the ATK Launch Systems test facility.[7] The test article had over 117 instrumentation channels to capture data for dozens of objectives. In addition to benefiting the Shuttle program, it also benefited the Ares V. As reported in Aviation Week and Space Technology, the extensibility from the Shuttle Reusable Solid Rocket Booster to the Ares V first stage “eliminates the need to start from square one. At the same time, it draws on workforce experience built up over the past quarter century.”[8] Another 2-minute booster test was conducted in November 2006 with instrumentation that will help analyze motor-induced roll-torque.

To facilitate RS-68 engine upgrade activities, the Ares V team in 2006 finalized a technical directive with Pratt & Whitney Rocketdyne (PWR) to evaluate the Core Stage Engine

requirement and review technical options, culminating in an Upgrades Requirement Review in October 2006. NASA and the engine contractor met to determine the best options for helium-use mitigation and to plan for analysis and testing. As an integral part of this engine effort, the Ares V team established a formal working relationship with the U.S. Air Force and the National Reconnaissance Office (NRO) to partner with the service on the RS-68 engine work, which is already in progress. The NRO plans to develop an upgraded RS-68A variant for a mission. From that variant, NASA would join with the Air Force to develop a common RS-68B version for use on both the Ares V and the Delta IV, featuring upgrades required by NASA for operability and changes planned by the Air Force for their Assured Access To Space program to improve robustness. Planned modifications to the current RS-68 are:

1. Increased power level to 108 percent from the current 102 percent.
2. Main injector changes to improve Isp to at least 414.2 seconds from the current 407.7.
3. New bearing material to decrease stress corrosion susceptibility.
4. Redesigned turbopump pump inlets to incorporate tip vortex suppression.
5. Redesigned fuel turbopump second stage blisk to decrease susceptibility to cracks.
6. Redesigned gas generator igniter that eliminates squib foreign object debris concern.
7. Higher reliability oxidizer turbopump bearing chill sensor.
8. Higher reliability hot gas sensor.
9. Redesigned oxidizer turbopump to reduce pre-start and operational helium usage.
10. Modified engine start sequence/configuration to reduce free hydrogen on the pad during engine start.
11. Redesigned ablative nozzle to accommodate the longer-duration Ares V mission profile.

The increased power level and main injector modifications are included in an engine upgrade program that PWR is implementing under a contract with United Launch Alliance for the RS-68A variant. Changes 3 through 8 are currently conducted under the Air Force Assured Access to Space Program. NASA will work with the Air Force to combine the AATS upgrades with changes 9-11 above, required for Ares V, to produce a common RS-68 B engine variant.

The J-2X Upper Stage Element was responsible for several important milestones in maturing the Ares V design in 2006. Engineers created many of the necessary planning and design documents needed to develop budgets, schedules, and design decisions. The Element completed a Preliminary Requirements Review in summer 2006 that concluded that engine requirements were mature enough to begin developing subsystem and component requirements and begin engine conceptual design. The team identified all existing J-2 engine hardware from the Apollo and X-33 programs and transferred them to the J-2X for refurbishment and testing. Test engineers conducted tests of a subscale main injector[9], an augmented spark igniter, J-2 heritage valves, and subscale tests of 40- and 58-element main injectors. The historic A-1 test stand at Stennis Space Center was transferred from the Space Shuttle Program to the Constellation Program for J-2X testing.

In November, the J-2X Element completed a combined System Requirements Review/System Definition Review that encompassed requirements, conceptual design, and planning to meet the exploration mission. Among the major decisions resulting from those reviews were discontinuation of a 274,000-pound thrust option to concentrate on the baseline 294,000-pound thrust option, selection of helium spin start over solid propellant gas generators, open loop control mode, pneumatic valve actuation, ball sector valves over heritage butterfly valves, and a baseline engine test plan.

That same month, NASA completed a milestone first review of all systems for the Orion spacecraft and the Ares I and Ares V rockets during a Constellation Program System

Requirements Review, the first system requirements review of a human rated spacecraft since the Space Shuttle in 1973.[10]

A series of engineering studies in 2006 and early 2007 served as the basis for an Ares V Integrated Vehicle Design Definition Document marking the completion of Design Analysis Cycle 0. This document, in turn, will serve as the starting point for one or more formal Design Analysis Cycles to follow. This DAC focused on refining the concept for the Core Stage. Refinements to the entire stack were made primarily where understanding the stack helped refine the Core Stage. Inputs to those studies included detailed computer aided design work (Figure 6).

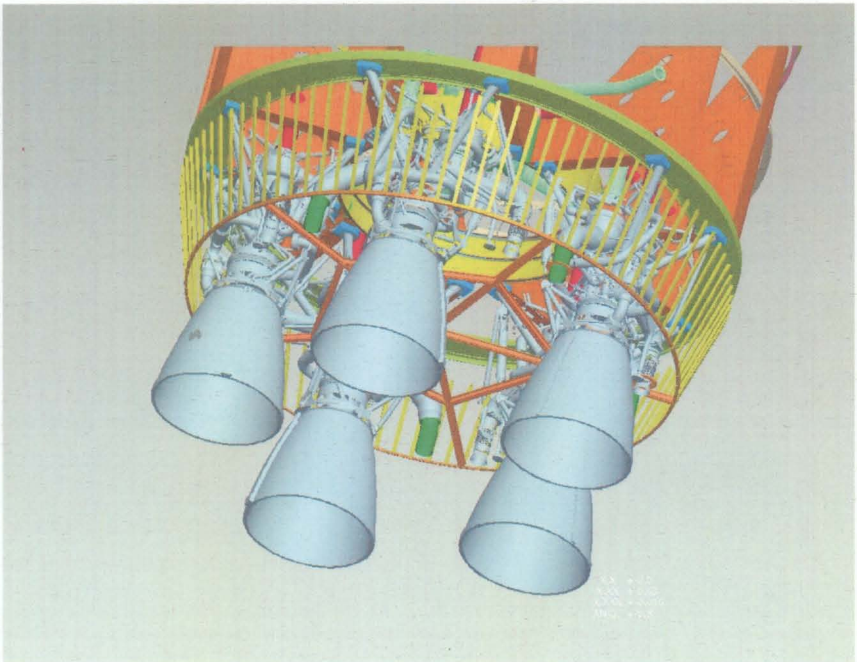

Figure 6. CAD concept art of Ares V Core Stage 5-around RS-68 engine configuration.

In early 2007, PWR completed a computational fluid dynamics analysis of free hydrogen accumulation around Pad 39 during launch, including a first transient case to 5 seconds and a second transient case at 3.4 seconds. The 5-second point is shown in Figure 7 below

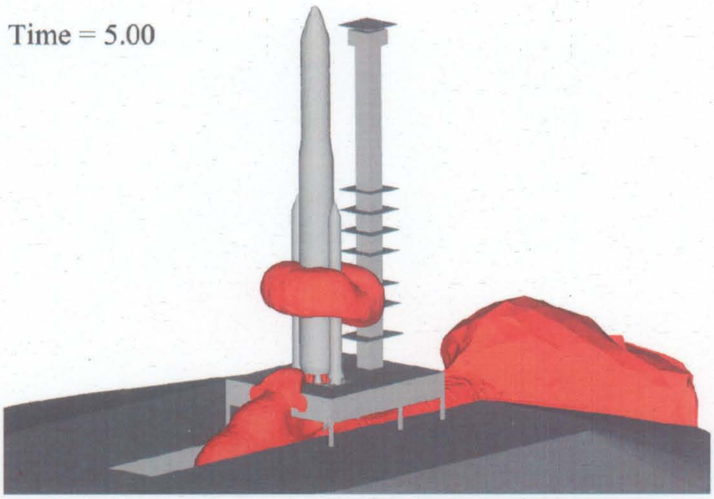

Figure 7. CFD analysis of launch pad free hydrogen 5 seconds after engine start.

An analysis of Michoud Assembly Facility was completed in March 2007 by the Austin Company. This study included manufacturing and assembly for Ares I Upper Stage, Ares V EDS and Ares V Core Stage. A planned follow-up study would assess surge capacity, manufacturing flow, tooling, and support equipment.

From January through March 2007, NASA Marshall engineers conducted multiple hot-fire tests of subscale RS-68 main injector hardware at MSFC Test Stand 116 (Figure 8). This first series of tests was performed on a subscale injector that contained 40 individual elements for propellant flow. During the tests, engineers fired the injector horizontally for durations of 10 to 20 seconds at varying fuel temperatures, mixture ratios, and velocity ratios. A similar test series using a 58-element main injector followed. The work will benefit the RS-68 A and B engines, as well as the J-2X, which will use the same injector.

Figure 8. Subscale 40-element injector test at MSFC.

As this paper was in preparation, several milestones important to the Ares V were scheduled for 2007, many important to the development of the RS-68B Core Stage Engine for the Ares V.

The Ares V team was scheduled to participate in the Air Force's RS-68A Preliminary Design Review in March 2007. A draft Interagency Agreement between NASA and the Air Force for RS-68B development was in the final stages of review. The Core Stage Element is also in the advanced stages of preparing a Statement of Work for an RS-68B Letter Contract that would extend through Upgrade Critical Design Review. It will define the work necessary for PWR to upgrade the RS-68 to function as the Core Stage engine. The J-2X Upper Stage Engine Element was also scheduled for a Resynchronization Review in March 2007 to resolve several issues remaining from SRR/SDR, including a final decision on a metal or composite nozzle extension that will allow the J-2X to attain its target thrust necessary for the lunar mission. The J-2X is slated for its Preliminary Design Review in June, and the first test of a J-2X power pack, including turbomachinery, gas generator, and inlet ducts, is scheduled to begin in November 2007.

SUMMARY AND CONCLUSIONS

The Ares V Cargo Launch Vehicle will deliver large-scale hardware and provisions to space for establishing a permanent Moon base and extending a human presence beyond the International Space Station and low-Earth orbit. Working in tandem with the Ares I/Orion combination, this heavy-lift vessel will provide a replacement for the venerable Space Shuttle. While NASA looks to the past for wisdom, it applies modern systems engineering and management practices and processes to ensure technical performance is delivered on time and within budget. Building on a foundation of legacy knowledge and heritage hardware increases the prospect of mission success in the complex business of space transportation.

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10 "NASA Completes Milestone Review of Next Human Spacecraft System." http://www.nasa.gov/mission_pages/constellation/ares/index.html

MSFC-053

National Aeronautics and Space Administration

Exploration Launch Projects

A New Heavy-Lift Capability for Space Exploration: NASA's Ares V Cargo Launch Vehicle

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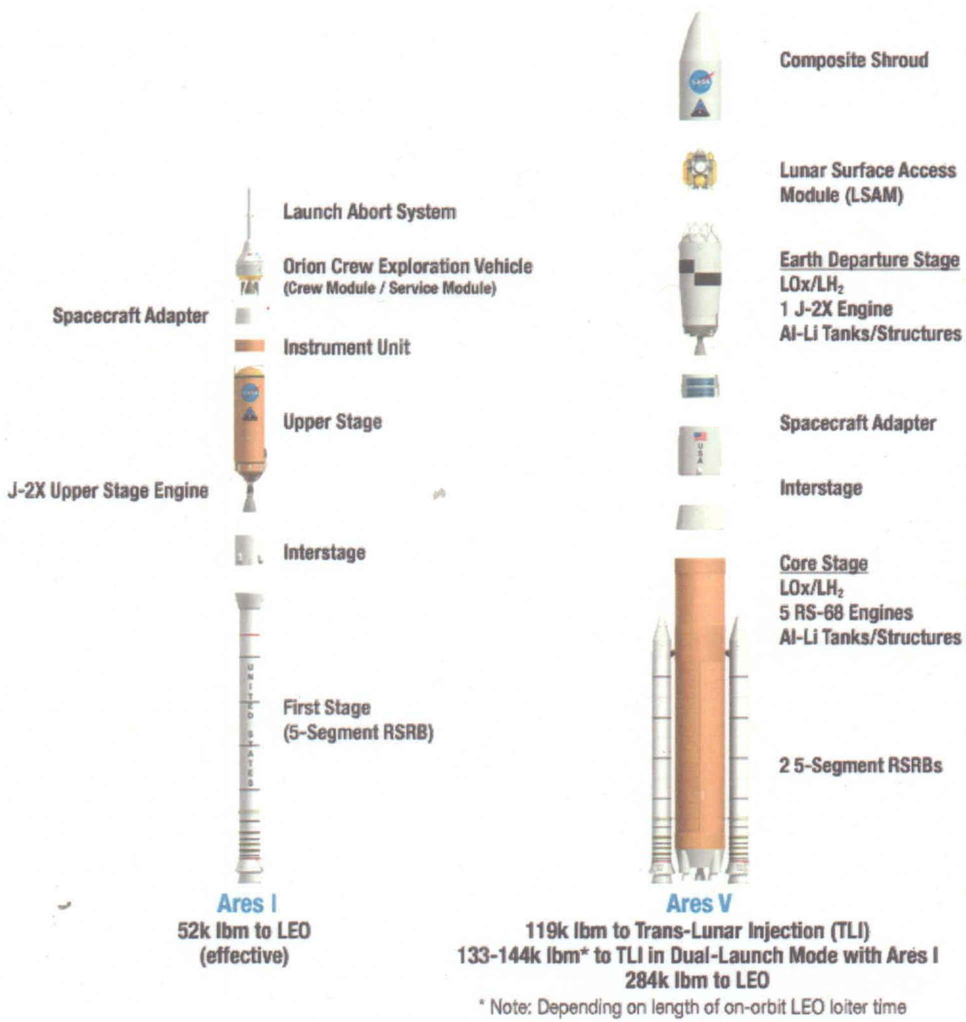
Agenda

- Overview of the Ares Launch Vehicles
- Ares V design approach & evolution
- 2006-2007 progress
- Forward work and conclusions

Overview of the Exploration Launch Projects Architecture

- Safe, reliable, affordable space transportation
- Based on heritage hardware and legacy knowledge
- Separates cargo from crew
- Ares V (left) delivers heavy exploration cargo to Low Earth Orbit (LEO)
- Ares I (right) delivers crew and cargo to LEO for International Space Station and lunar missions

Exploration Launch Projects Architecture (cont'd)



Shared heritage, shared hardware

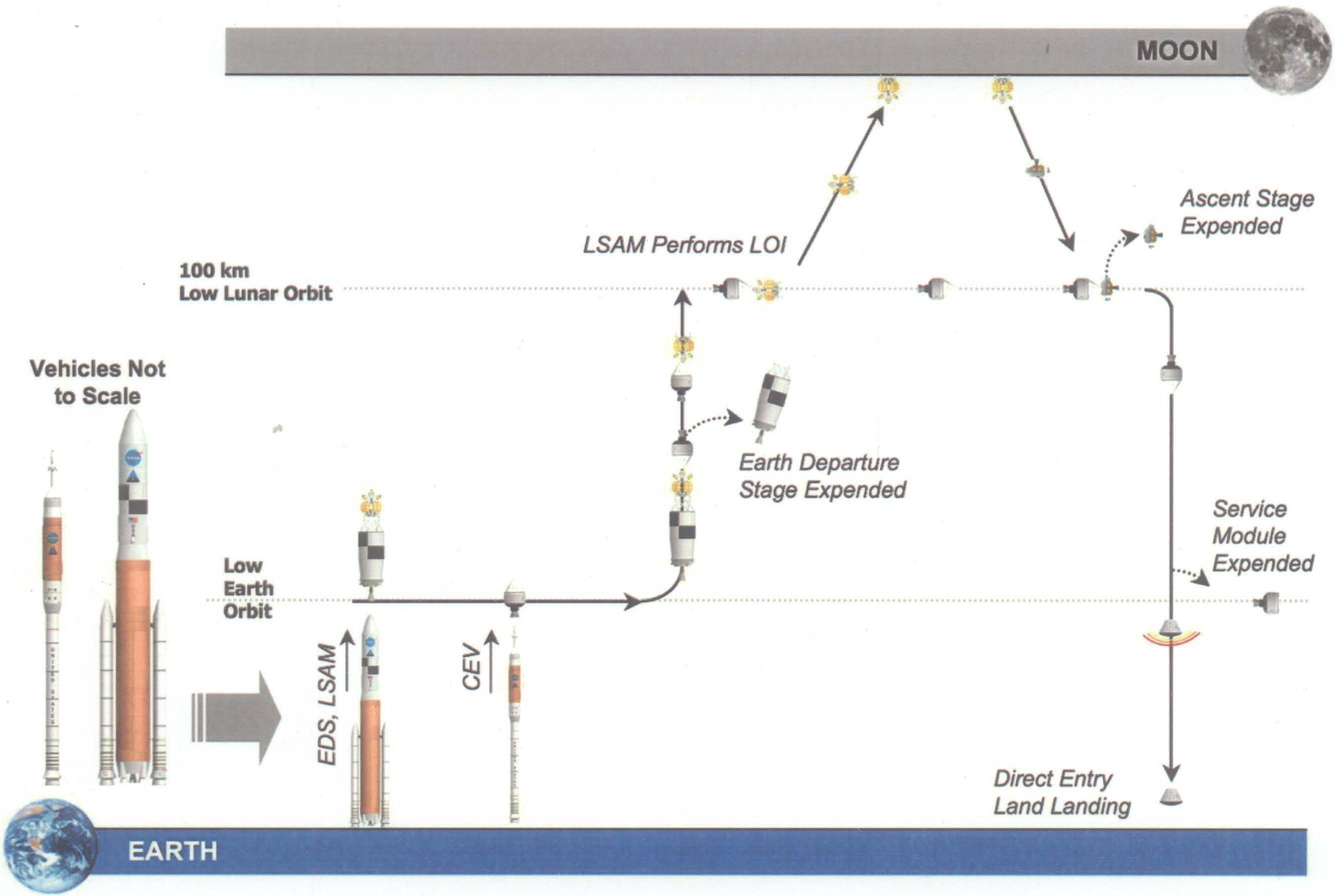
- **Ares I**
  - 1 Shuttle-derived Reusable Solid Rocket Booster (RSRB) First Stage
  - 1 J-2X LOx/LH_2 Upper Stage Engine

Ares V

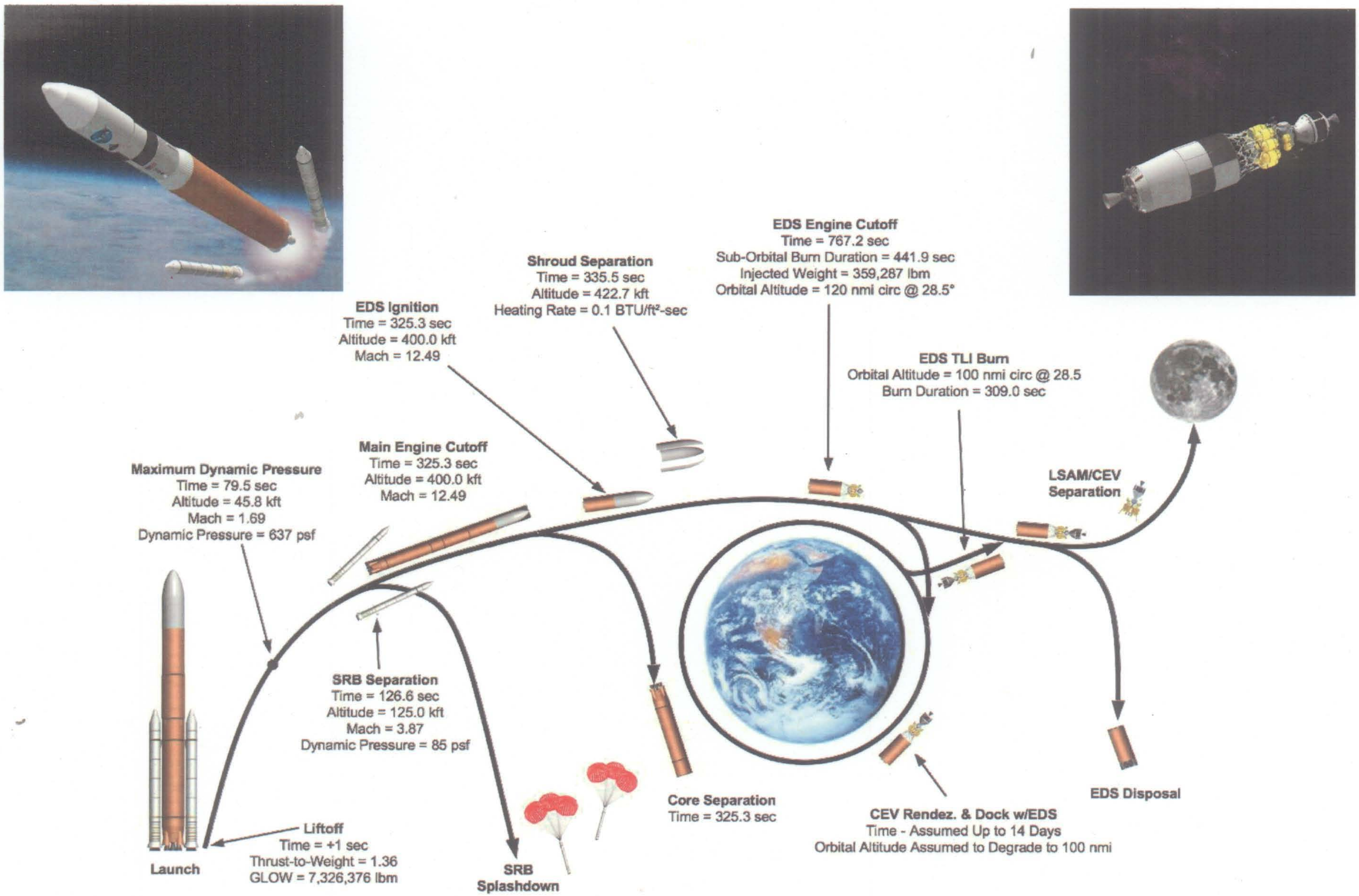
- **Core Stage**
  - 5 RS-68 LOx/LH_2 Core Stage engines
  - 2 Ares I-derived RSRBs
- **Earth Departure Stage (EDS)**
  - 1 J-2X LOx/LH_2 Upper Stage Engine

  - Common hardware and procedures with Ares I to reduce development and operations costs

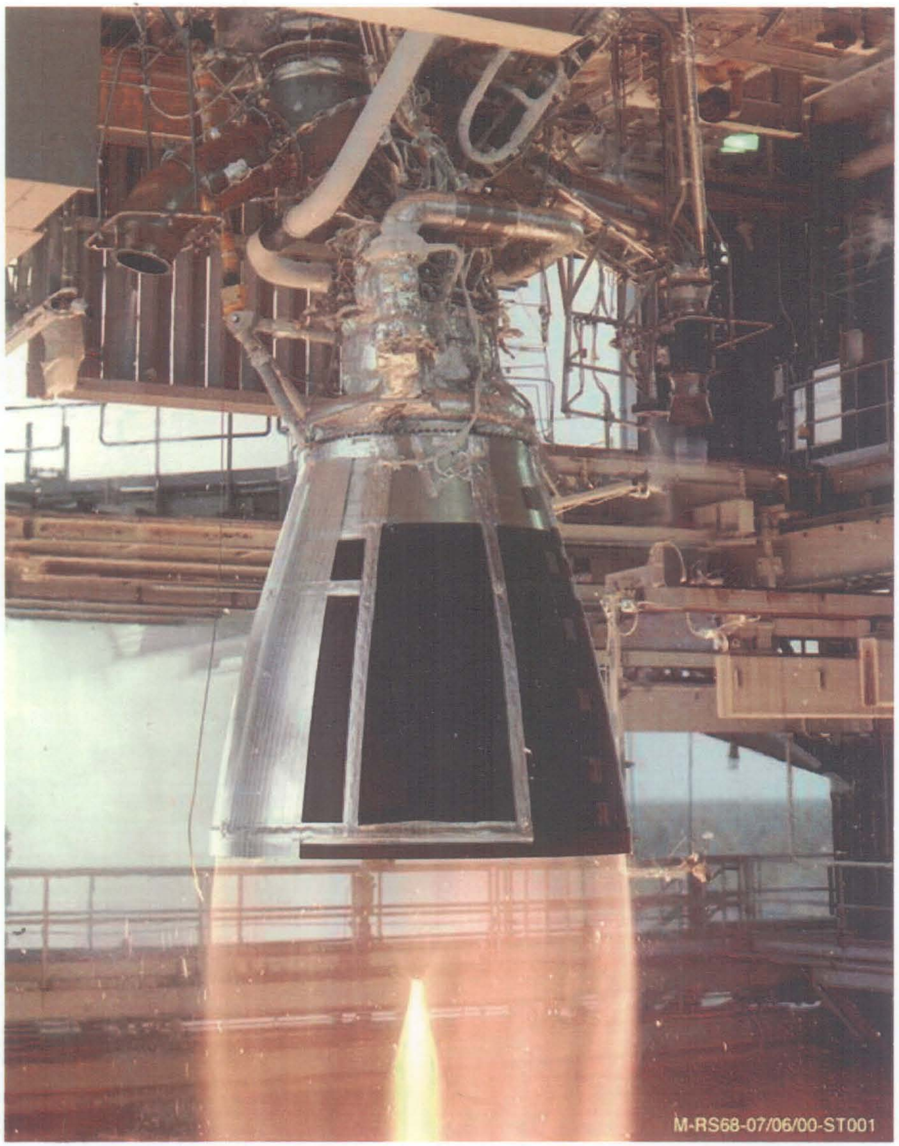
The Lunar Mission Scenario



Ares V mission profile



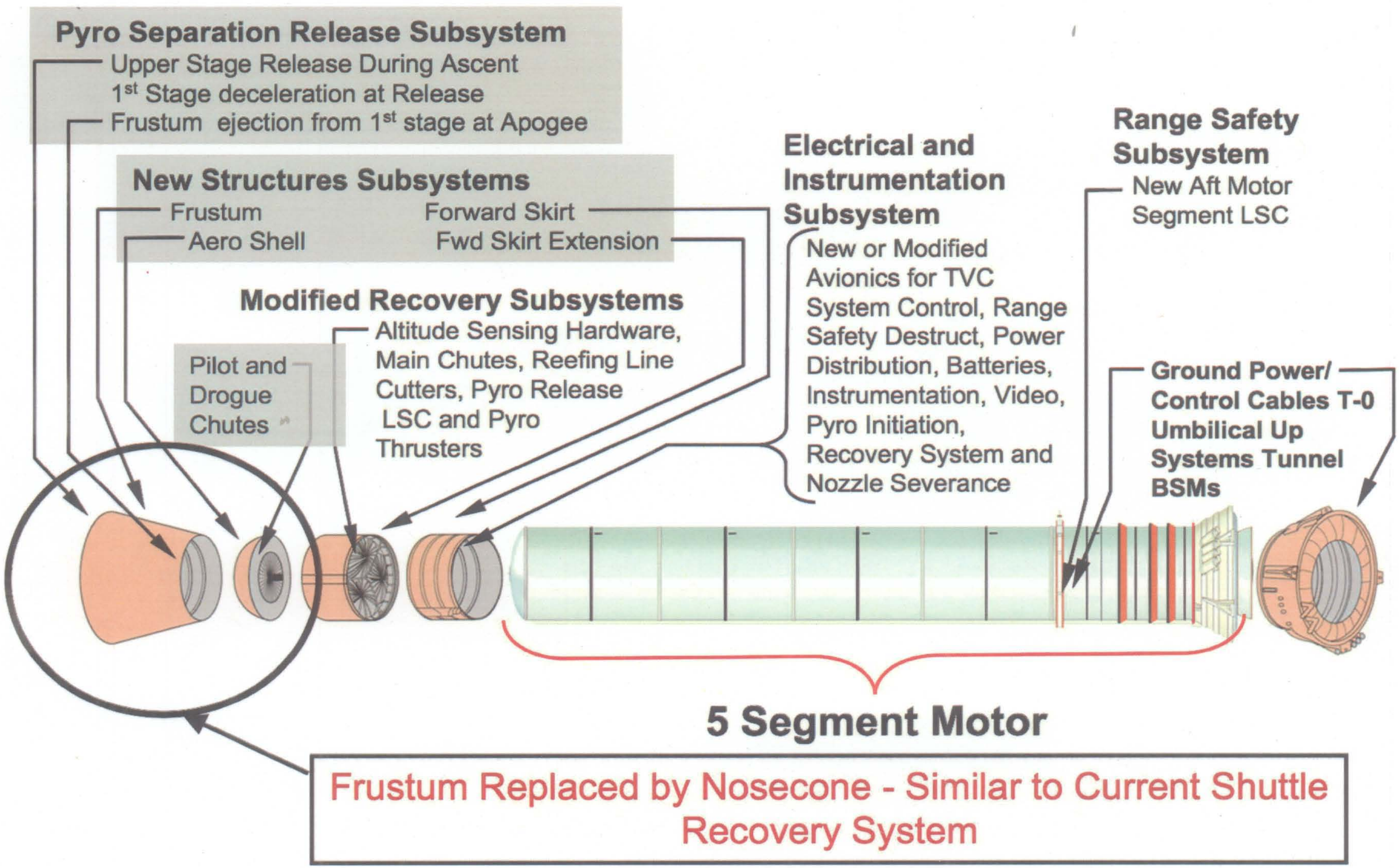
Refining the Concept



- **Exploration System Architecture Study**
  - Ares V baseline: 2 RSRBs, 5 Space Shuttle Main Engines (SSMEs), 27.5 foot diameter Shuttle-derived Core Stage

- **Bottom-Up Review**
  - RS-68 Expendable Exploration Launch Vehicle (EELV) engine replaces SSME
    - Fewer parts
    - Less labor
    - Simpler to modify
    - Synergy with USAF engine upgrades
    - Delta IV flight experience reduces technical risk
  - 33 foot diameter Saturn V-class Core Stage

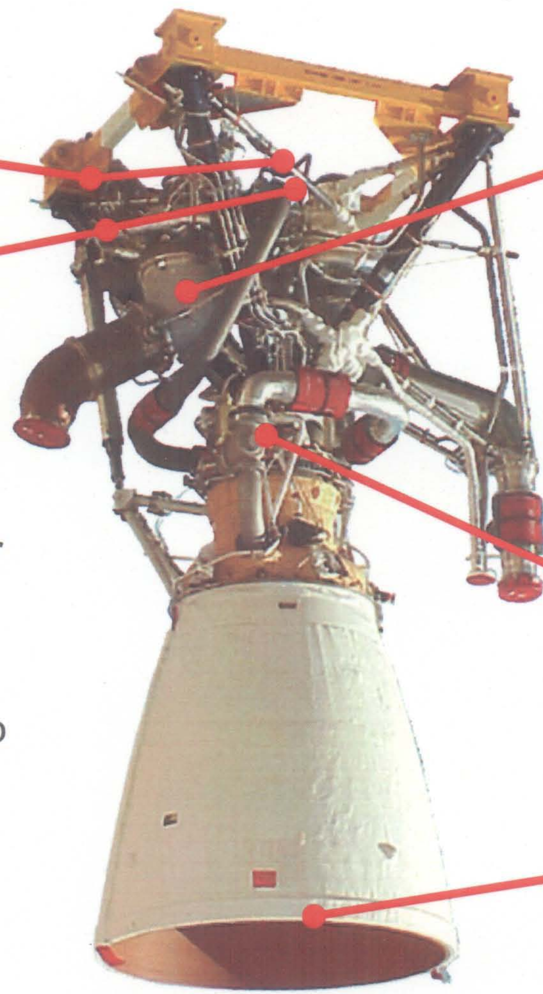
Commonality:
Ares I First Stage to Ares V Booster



Heritage Hardware: RS-68 Upgrades

* Redesigned turbine nozzles to increase maximum power level by ≈ 4%

Redesigned turbine seals to significantly reduce helium usage for pre-launch



Helium spin-start duct redesign, along with start sequence modifications, to help minimize pre-ignition free hydrogen

* Higher element density main injector improving specific impulse by ≈2%

Increased duration capability ablative nozzle

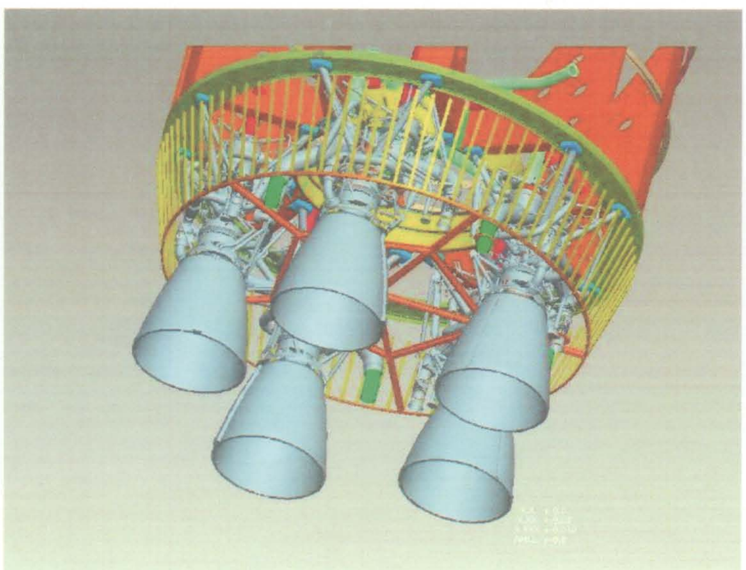
Other Changes in RS-68A upgrades or that may be included:

- Bearing material change
- New Gas Generator igniter design
- Improved Oxidizer Turbo Pump temp sensor
- Improved hot gas sensor
- 2nd stage Fuel Turbo Pump blisk crack mitigation
- Cavitation suppression
- ECU parts upgrade

* **RS-68A Upgrades**

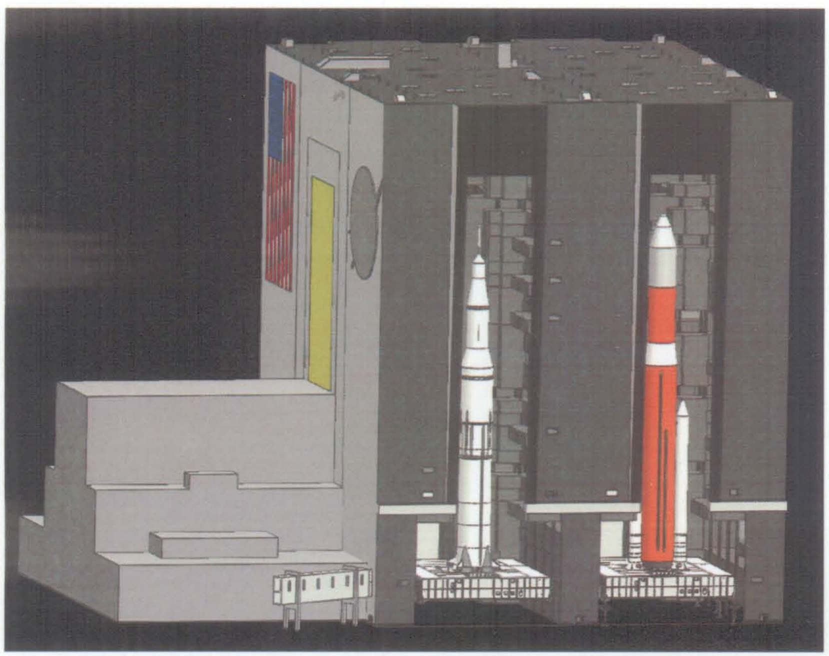
Progress and Plans

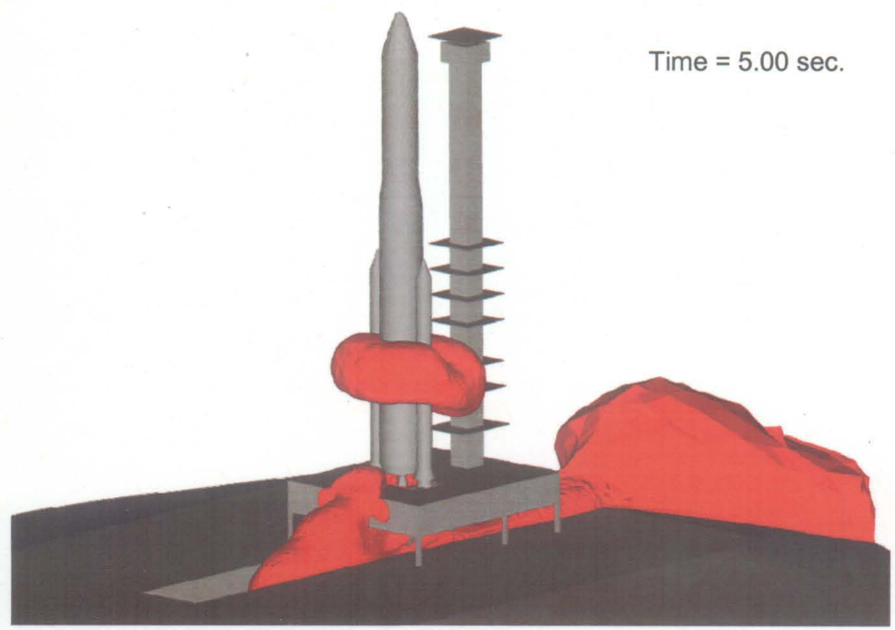
- Obtained "Seed money" for early development
- Developed integrated master schedule
- Prepared Concept of Operations document
- Performed Core Stage design studies



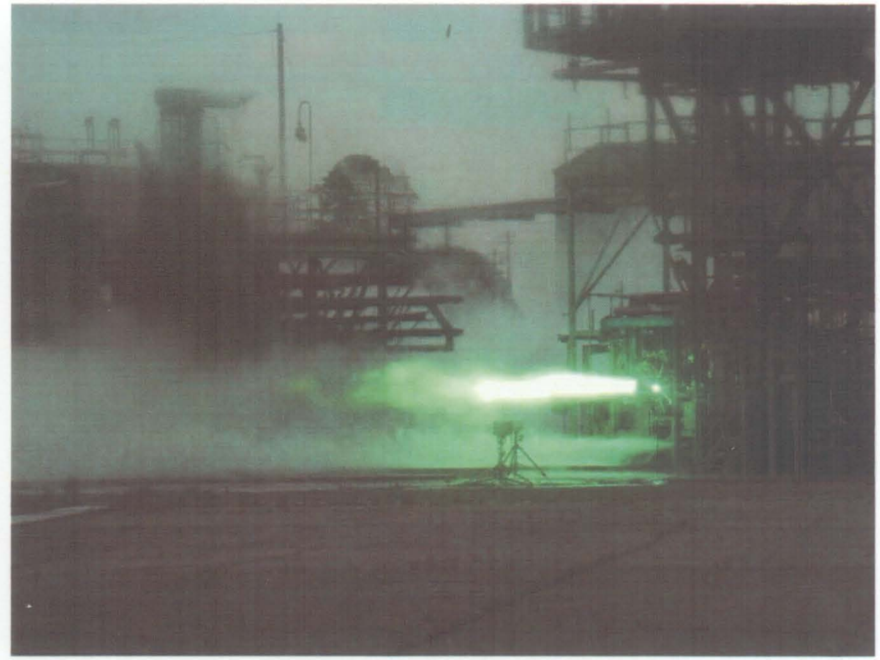
Progress and Plans (cont'd)

- Facilities studies – Michoud Assembly Facility (MAF), Stennis Space Center (SSC), Kennedy Space Center (KSC)
- Free hydrogen study



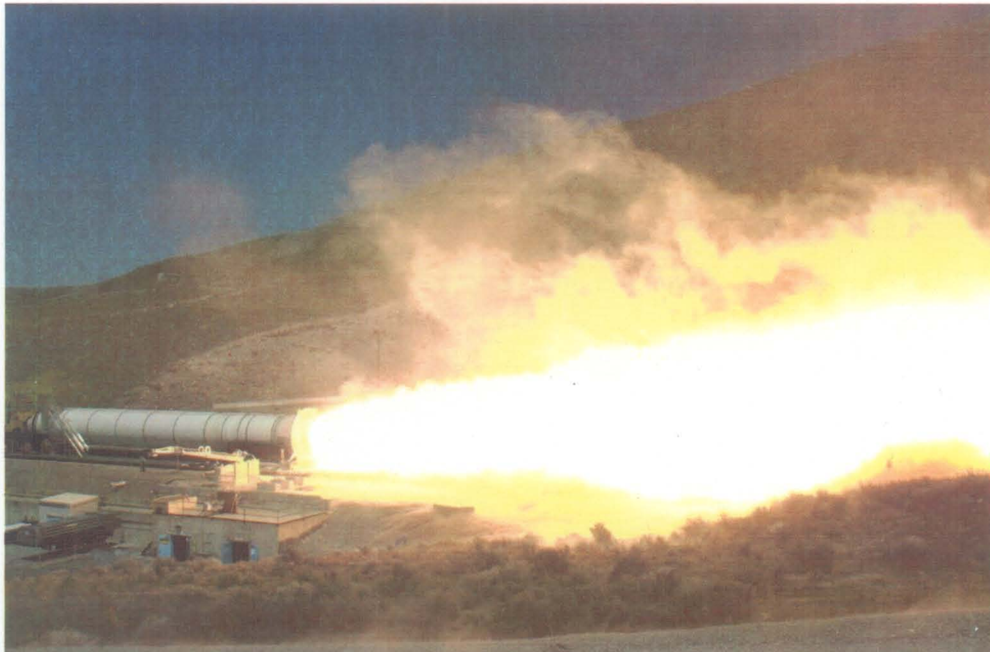


Early Testing

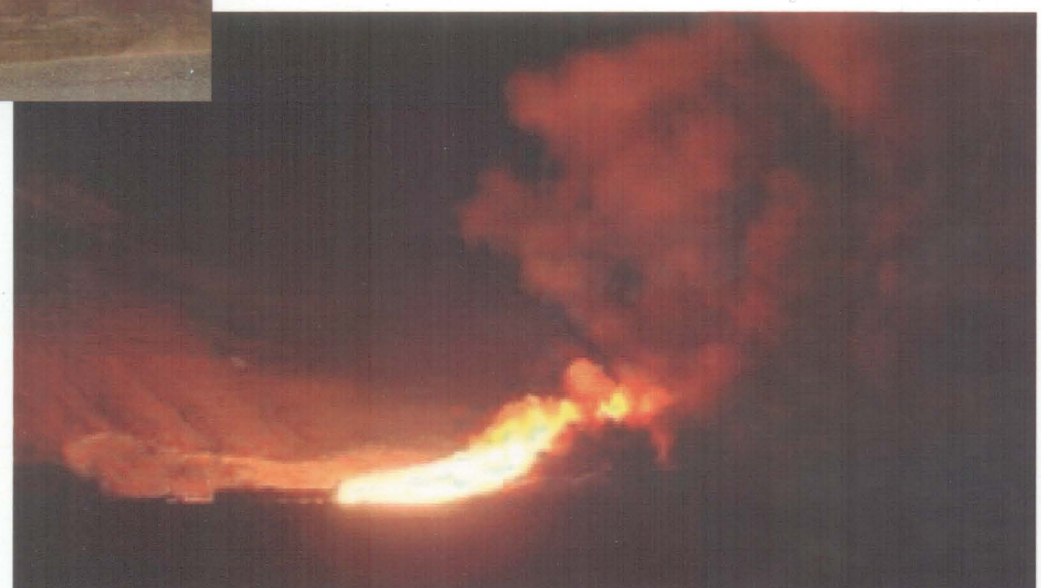


- RS-68 (left) and J-2X (right) subscale injector testing at MSFC, 2006-2007
- 29 RS-68-focused, 32 J-2X-focused
- 28-, 40-, & 58-element injector inserts
- Thrust levels: less than 20,000 lbf
- Chamber pressures: 850-1,500 psig
- Mixture Ratios: 4.8-6.9
- Fuel manifold temperatures: 100-300°.Rankin
- Commonality!

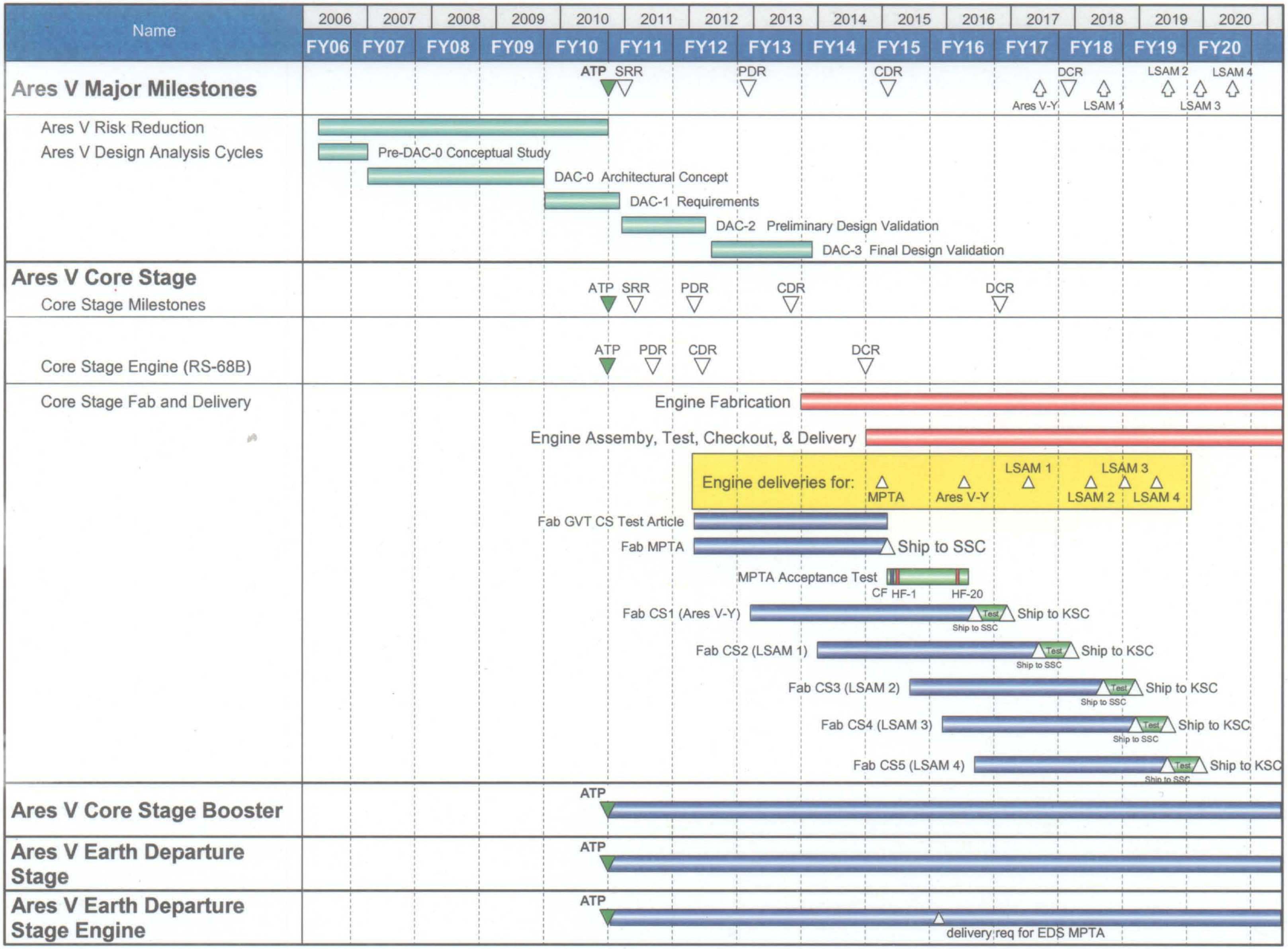
2006 RSRB tests



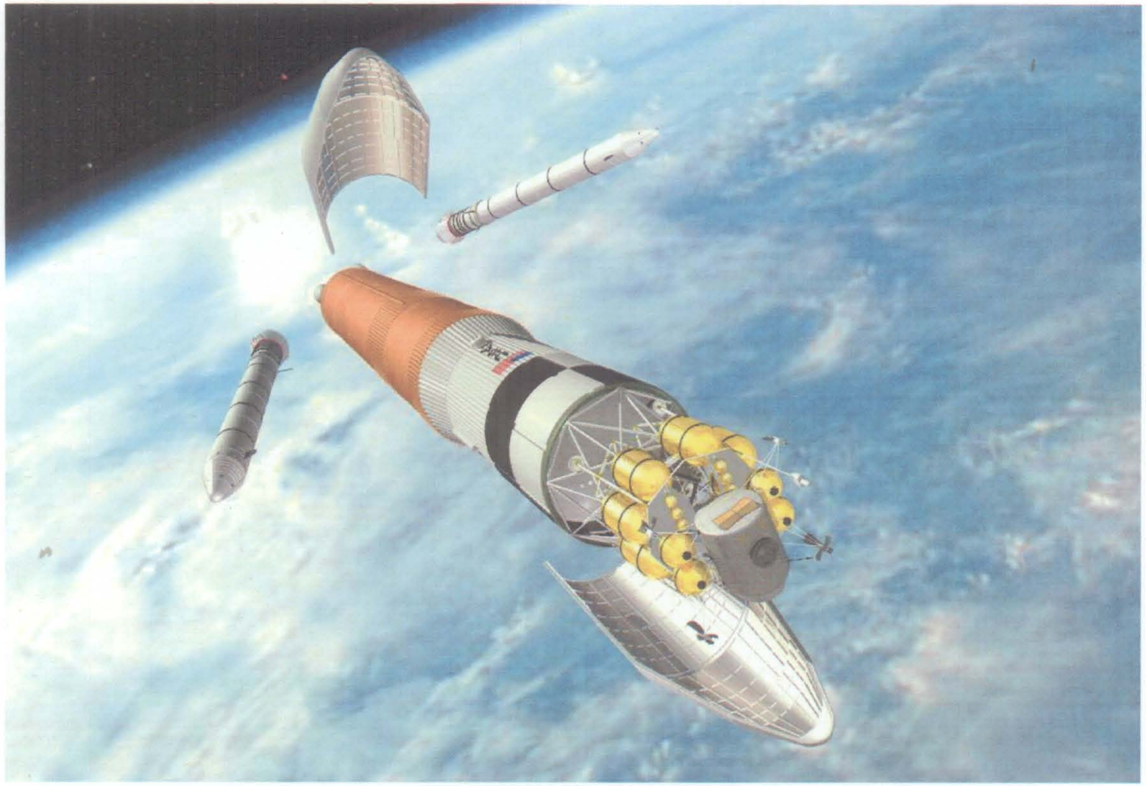
- April (left) and November (below) tests obtain data on internal roll torque, material/design changes for Shuttle, Ares I and Ares V
- Commonality!



Ares V Consolidated Schedule



Summary



- Ares V remains the heavy-lift component of NASA's exploration architecture and a key component of "national strategy"

For More Information

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Ares public website

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Questions?

www.nasa.gov/ares